A Micro Vertex System in a EIC Detector based on Monolithic Active Pixel Sensors

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DEPARTMENT OF ENERGY • UNITED STATES OF AMERICA

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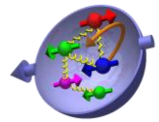
Most Compelling SCIENCE Questions at an EIC

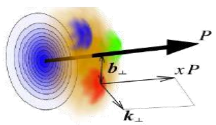
spin physics



- what is the polarization of gluons at small x where they are most abundant
- what is the flavor decomposition of the polarized sea depending on x

determine quark and gluon Contributions to the proton spin at last

imaging

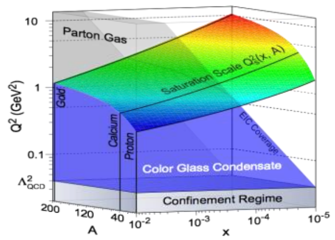


- what is the spatial distribution of quarks and gluons in nucleons/nuclei
- understand deep aspects of gauge theories revealed by k_T dep. distribution

possible window to orbital angular momentum

physics of strong color fields

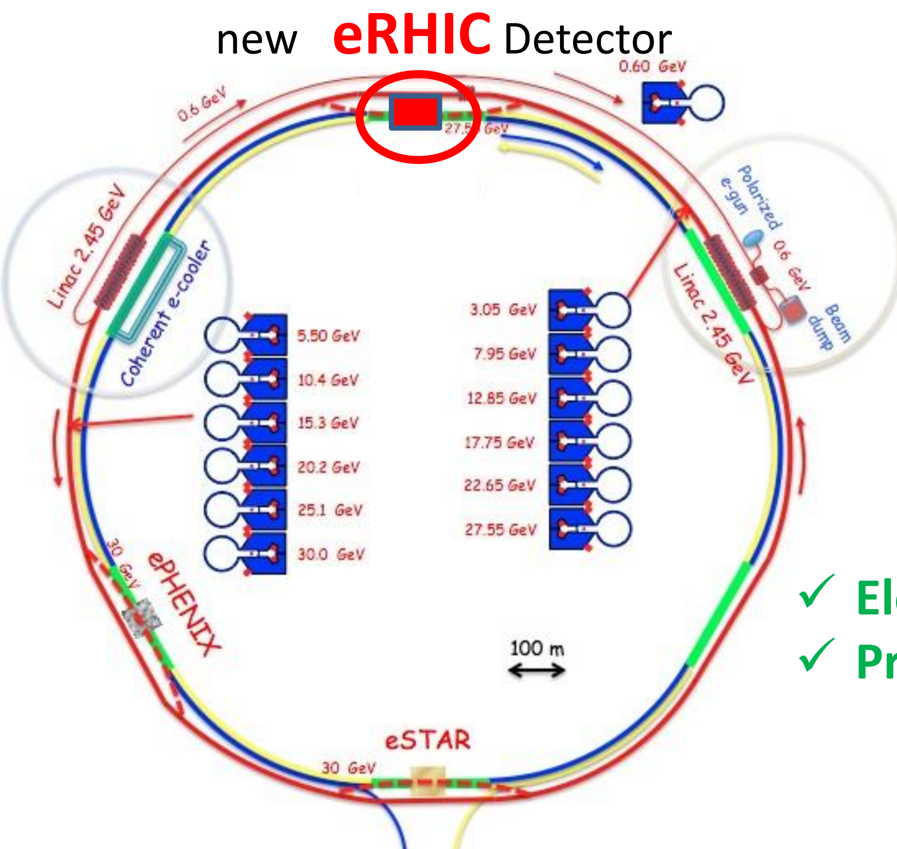
quantitatively probe the universality of strong color fields in AA, pA, and eA



- understand in detail the transition to the non-linear regime of strong gluon fields and the physics of saturation
- how do hard probes in eA interact with the medium

For details see in this meeting: **Session KE: Mini-Symposium on the Physics Program at EIC**
http://meetings.aps.org/Meeting/DNP13/Session/KE

eRHIC: an EIC collider at BNL

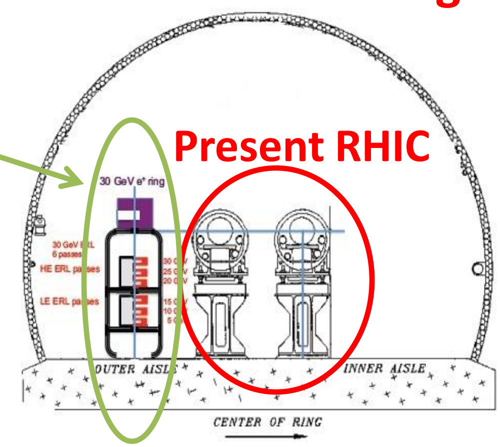


Collisions:

- ✓ Polarized electrons : 10, 20, (30?) GeV
- ✓ Polarized protons :75, 250 GeV
- ✓ Ions. 50, 100 GeV/u

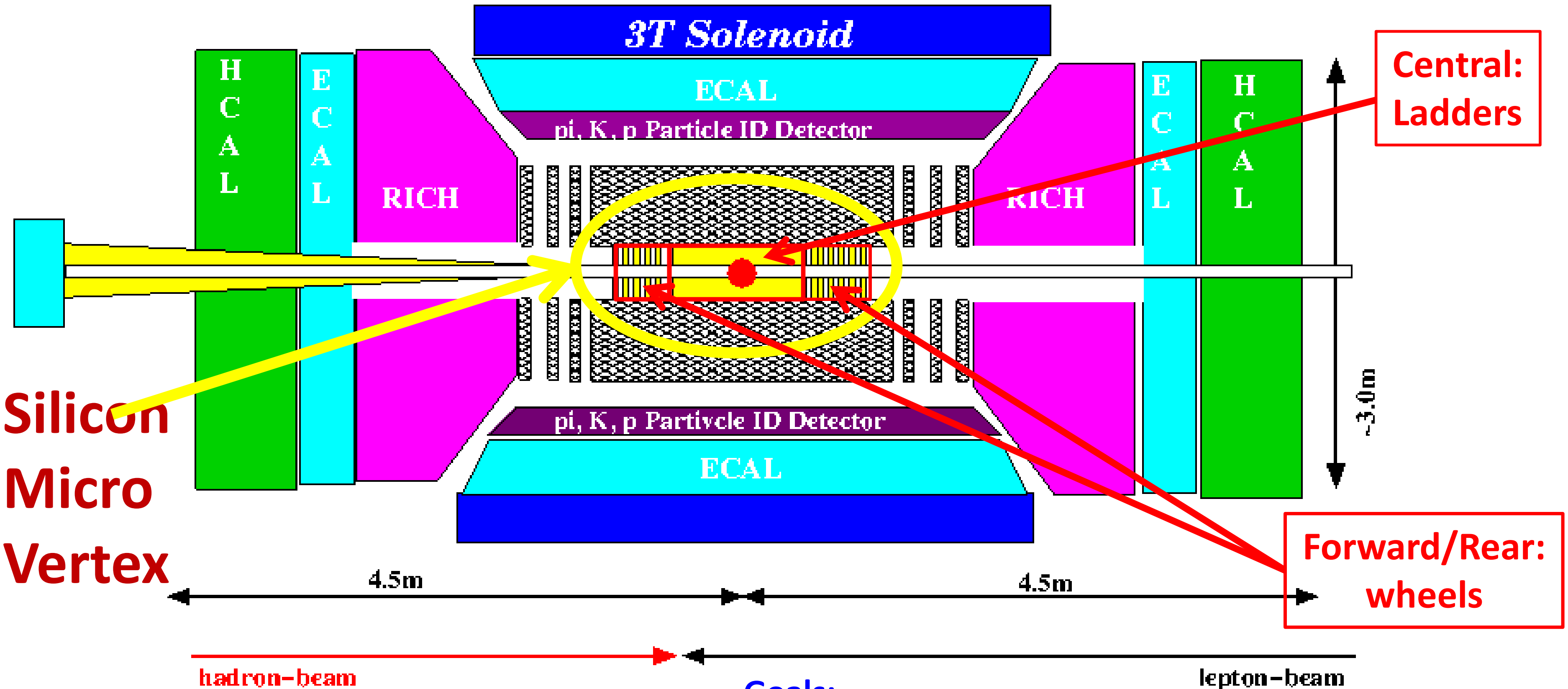
Keypoints:

- ✓ Electron beam: NEW High Energy ERL.
- ✓ Proton beam: NEW coherent electron cooling.



- ✓ No other tunnel required: electron beam line will be added in the present RHIC tunnel.
- ✓ Up to 3 experimental locations available.

Overview of the New eRHIC Detector



Goals:

high acceptance -5 < η < 5 central detector

good PID (π,K,p and lepton) and vertex resolution (< 5μm)

tracking and calorimeter coverage the same → good momentum resolution, lepton PID

low material density → minimal multiple scattering and brems-strahlung

very forward electron and proton/neutron detection → maybe dipole spectrometers

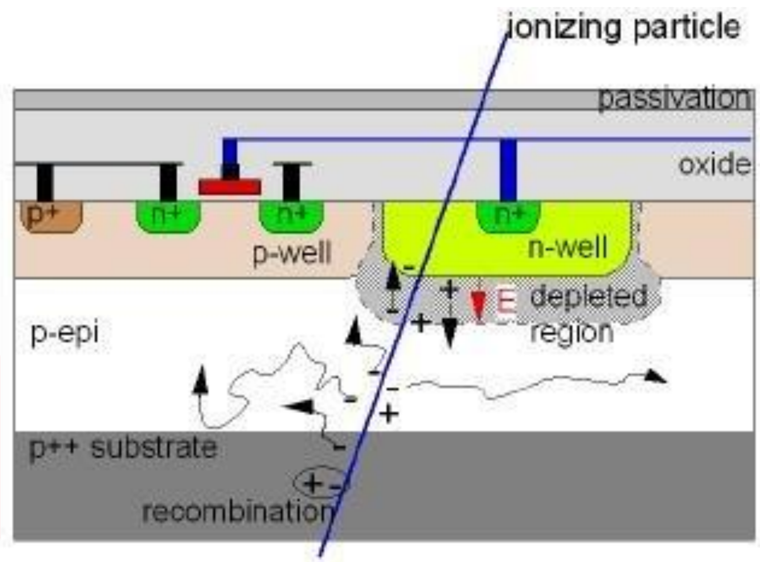
See Alexander Kiselev talk for more details on detector simulation:

http://meetings.aps.org/Meeting/DNP13/Session/DG.4

A Silicon Micro Vertex for eRHIC

Vertex system based on Monolithic Active Pixel Silicon Sensor (MAPS)

MAPS type candidate: MIMOSA



Tests ongoing at BNL:

MAPS MIMOSA26 (digital output) designed in the Institut Pluridisciplinaire Hubert Curien,Strasbourg (FR).

www.iphc.cnrs.fr/-PICSEL-.html

Keypoints:

- ✓ **All the sensor is produced using a standard CMOS technology.**
- ✓ **No Bump bonding required.**
- ✓ **Works at room temperature: low cooling material budget.**
- ✓ **Low bias voltage required: electrons are collected for thermal diffusion.**
- ✓ **High segmentation: pixel dimension ~20x20 μm^2**

A Silicon Micro Vertex Detector for eRHIC

MIMOSA26 (developed for the EUDET beam telescope): used in our test

- **0.35µm CMOS process (AMS: up to 4 metal layers), with high-resistivity epitaxial layer**
- **Column architecture with in-pixel amplification (CDS) and end-of-column discrimination, followed by zero suppression →binary charge encoding**
- **Read-out in rolling shutter mode**
- **Active area: 1152 columns of 576 pixels (21.2×10.6 mm ^2)**
- **Pitch: 18.4 µm~0.7 million pixels**
- **2 outputs at 80 MHz (Data1 and Data2)**
- **Power consumption ~250 mW/cm^2 (~520 µW/colum)**
- **Array readout time 112 µs**

MIMOSA28 (Ultimate): used in the STAR PXL upgrade

- **Same 0.35µm CMOS process, different design of the array, keep all the other features**

MIMOSA32 and MIMOSA34: prototype under studies

- **0.18µm CMOS process (TowerJazz: up to 6 metal layers), with high-resistivity thick epitaxial layer (18-40 µm)**
- **All the feature of the MIMOSA26 and MIMOSA28**
- **Studies ongoing to reduce the readout time to 30/40 µs, best candidate for a EIC detector for radiation hardness and thickness of sensors**
- **Best candidate for silicon MAPS wheel because the two extra metal layers allows non square geometries of the pixels array with a rolling shutter read-out**
- **Also approved for ITS ALICE upgrade, candidate for CBM and ILD detectors**

For the cooling system we are exploring the possibility of a micro channeling technology

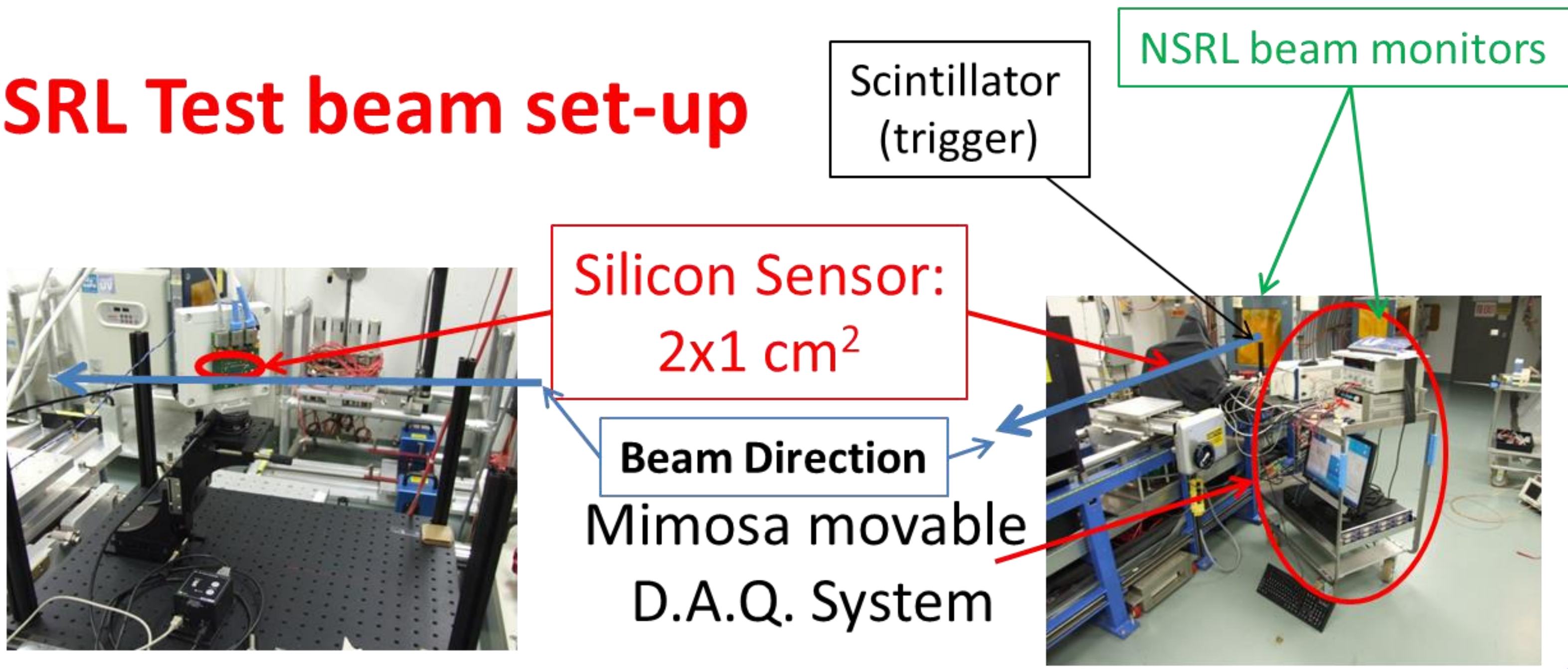
The BNL NASA Space Radiation Laboratory

In this Lab there is one of the few beam-lines able to deliver many different type of ions. This beam line is mainly devoted to irradiation studies of electronic devices and biological tissue. We decided to make a test in this beamline in order to investigate the possibility of comparing the clustering in the sensor using different type of ions.

Beam-line characteristics:

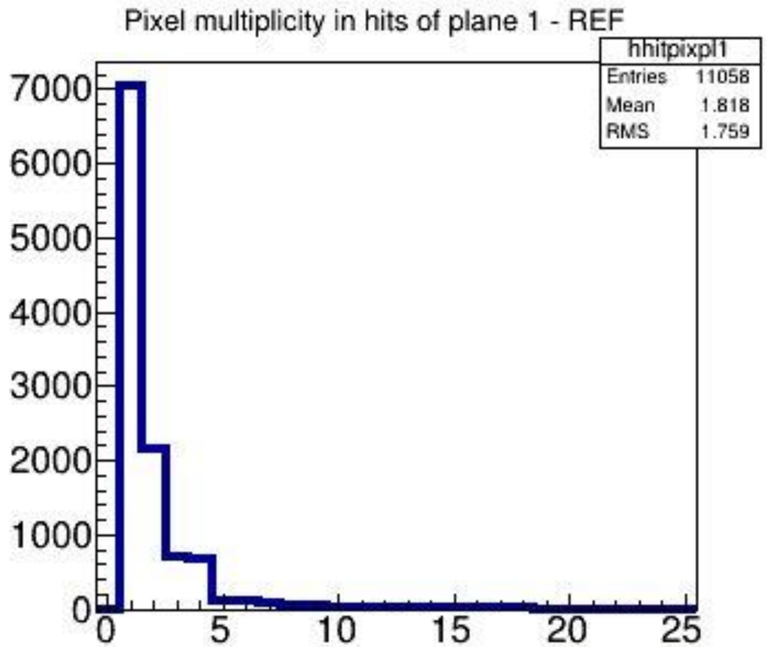
1)beams of protons/heavy ions extracted from the BNL Booster accelerator
2)Available ions beams: iron-56, gold-97, silicon-28, protons, titanium, carbon
3)Beam spot tunable from few mm^2 up to 10x10 cm^2 with spill duration of 0.2 s every 4s
4)Number of particle tunable until few/spill

NSRL Test beam set-up



Irradiation with protons beam

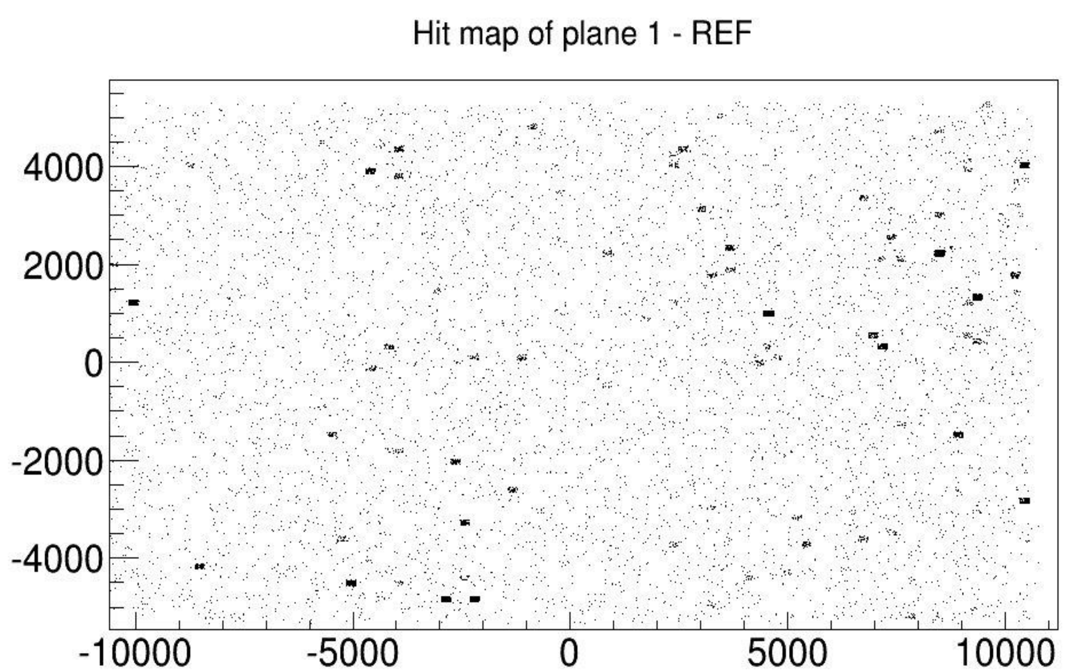
(Frame= one read-out of the whole pixel array)*



Clustering in 50000 frames*

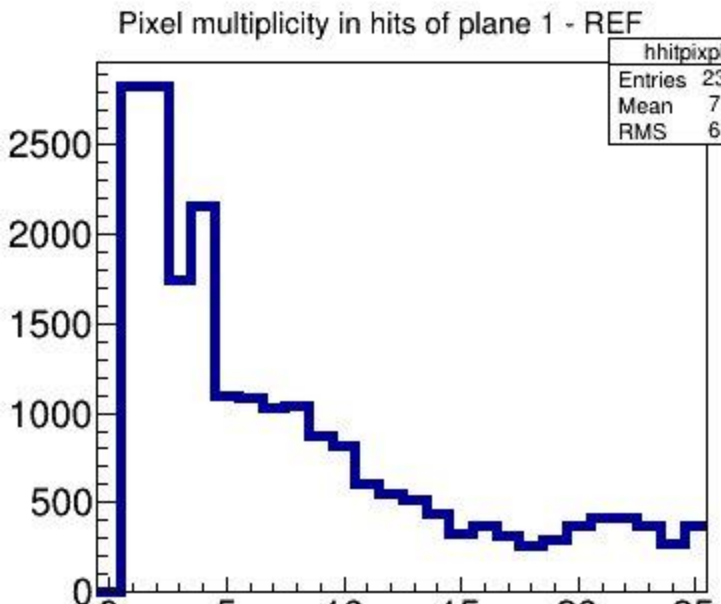
- Proton Energy: 1GeV
- DAQ Trigger: Fixed 8.68 kHz
  (no spill synchronization)
- Beam intensity :5000 particles/spill cm^2
- Beam spot 5x5 cm^2

Hits distribution in 50000 frames
(X,Y axis= um of one pixels array)
High noise due to lots of empty frames
(no synchronization)



➢ Very high noise observed with this trigger configuration.

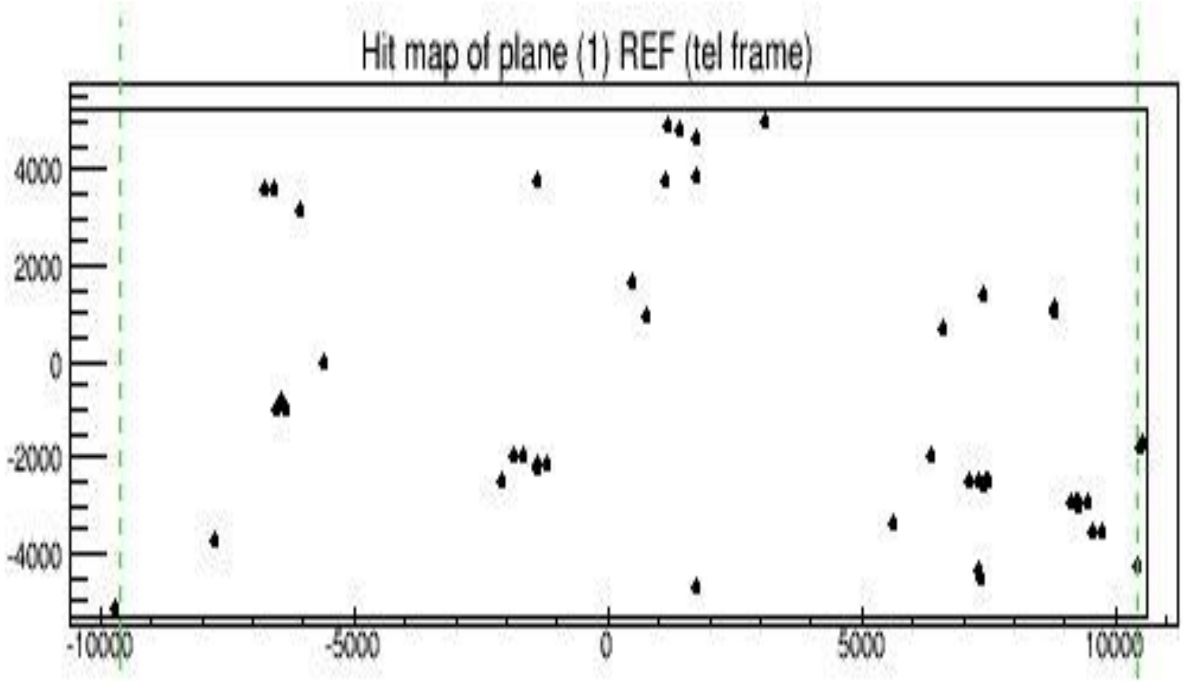
Irradiation with Silicon ions



Clustering in 700 frames

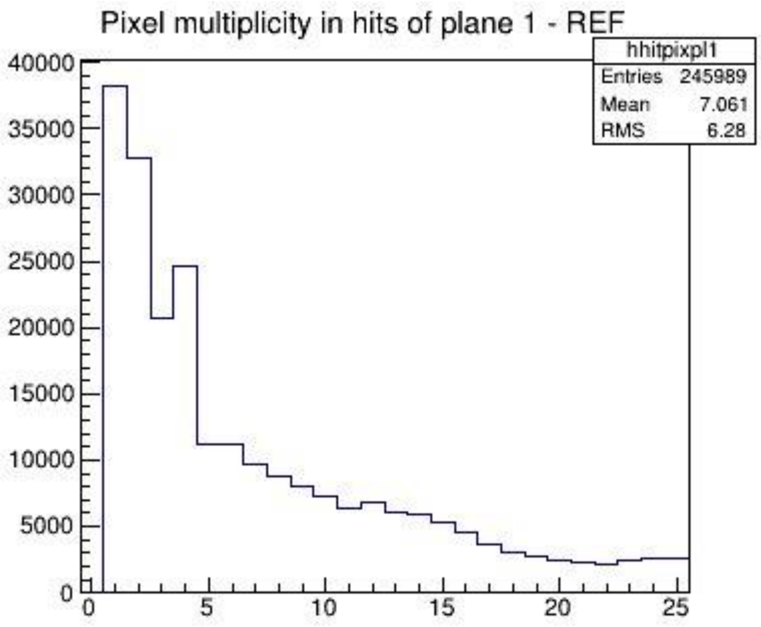
- Silicon Ion Energy: 600MeV/u
- Sensor orientation:45 degree
- DAQ Trigger: Fixed 4kHz
  (with spill synchronization)
- Beam intensity :60000 particles/spill cm^2
- Beam spot 5x5 cm^2

Occupancy in only one frame



- Noise better than the other trigger configuration but still high
- No saturation in the DAQ bandwidth

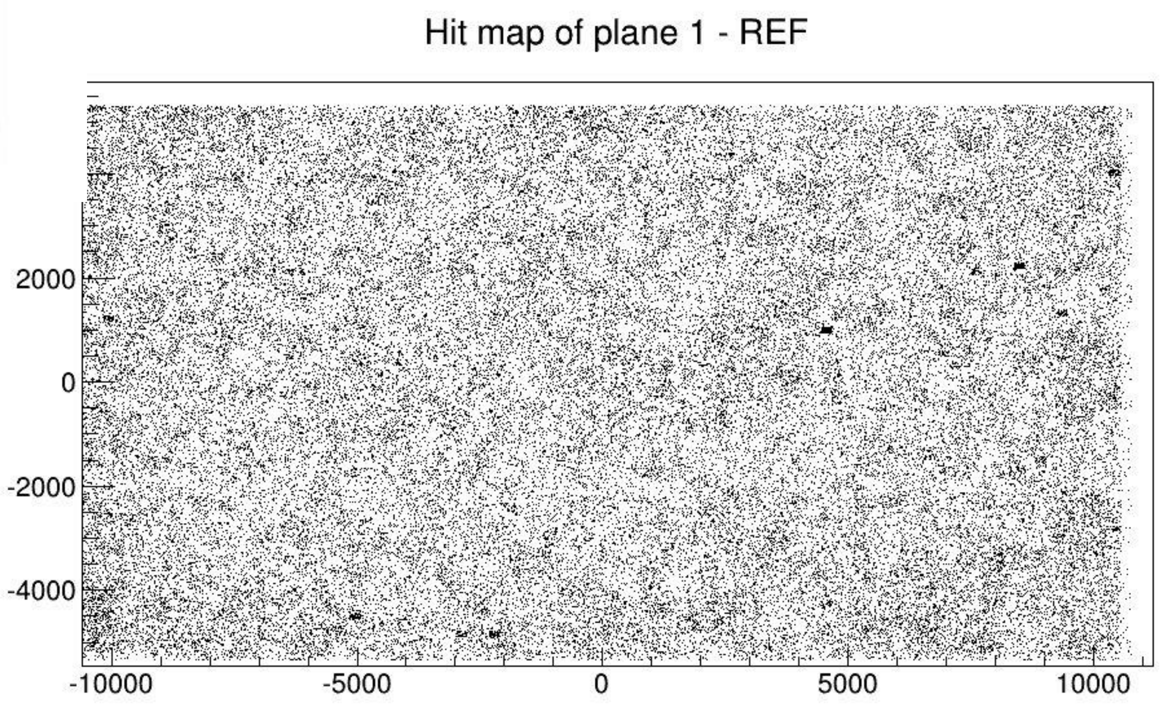
Irradiation with Iron beam



- Iron Ion Energy: 1GeV/U
- Sensor orientation:45 degree
- DAQ Trigger: Fixed 4kHz
  (with spill synchronization)
- Beam intensity :7000 particle/spill cm^2
- Beam spot 5x5 cm^2

Clustering in 50000 frames

Clustering in 10000 frames



- Still high noise, investigation required on hot/noise channels.
- Good DAQ performance

Conclusions

The present status of the MAPS technology confirms this silicon sensor type as the

- best candidate for the inner tracking of a EIC/eRHIC detector.
- The new 0.18 CMOS technology and the new design reduce a lot the readout time of the array.
- The new 6 metal layers technology and the radiation hardness is the key for the construction of the wheels with MAPS technology, something completely new.
- These wheels, with low mass will allow to high resolution: ideal to get a good $\Delta p/p$ in the forward direction.
- In BNL we have unique beam-line to develop these kind of prototypes and we are developing the know-how to do this.
- In this first test with MAPS under ion beams we realized that the noise level in the spare chip used was to high for good measurements, but we define the procedure to do this type of tests.

PLANS:

In the future we want repeat these test with the new prototype MIMOSA32 and MIMOSA34 with digital and analog readout.

Thanks for your attention !

- **This work was possible only thanks the efforts , the collaboration and help of all the BNL NSRL members, a special thanks to Michael Sivertz, Adam Rusek, Chiara La Tessa and Marta Rovituso.**
- **Thanks to the PICSEL group (IPHC-CNRS Strasbourg) for the help and the support.**
- **This work was supported with BNL LDRD project #11-036**

Links to EIC related information

- **eRHIC BNL home page**

https://wiki.bnl.gov/eic

- **eRHIC BNL Collider Accelerator Department**

http://www.bnl.gov/cad/eRhic/

- **EIC White Paper**

http://arxiv.org/abs/1212.1701

- **NASA Space Radiation Laboratory at Brookhaven**

http://www.bnl.gov/medical/nasa/nsrl_description.asp

- **EIC Montecarlo page**

https://wiki.bnl.gov/eic/index.php/Simulations

- **Call for EIC R&D proposals**

https://wiki.bnl.gov/conferences/index.php/EIC_R%25D

- **EIC R&D Simulation workshop (BNL October 8TH -9TH 2012)**

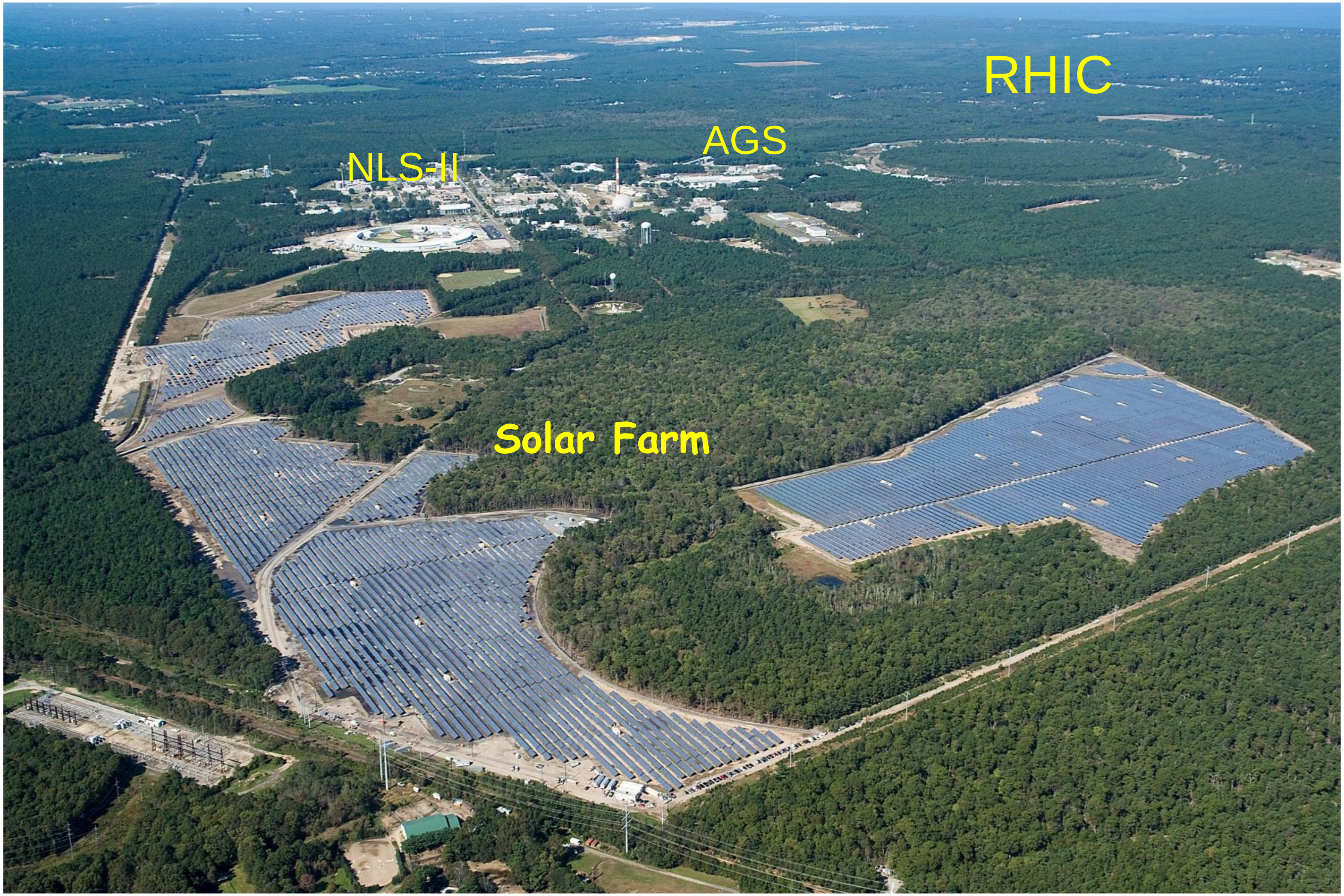
https://wiki.bnl.gov/conferences/index.php/EIC_RD_Simulation/Agenda

- **Gluons and quark sea at high energies:**

Report on a ten week program that toke place at the Institute for Nuclear Theory (Seattle, Fall 2010) http://:arxiv/abs/1108.1713

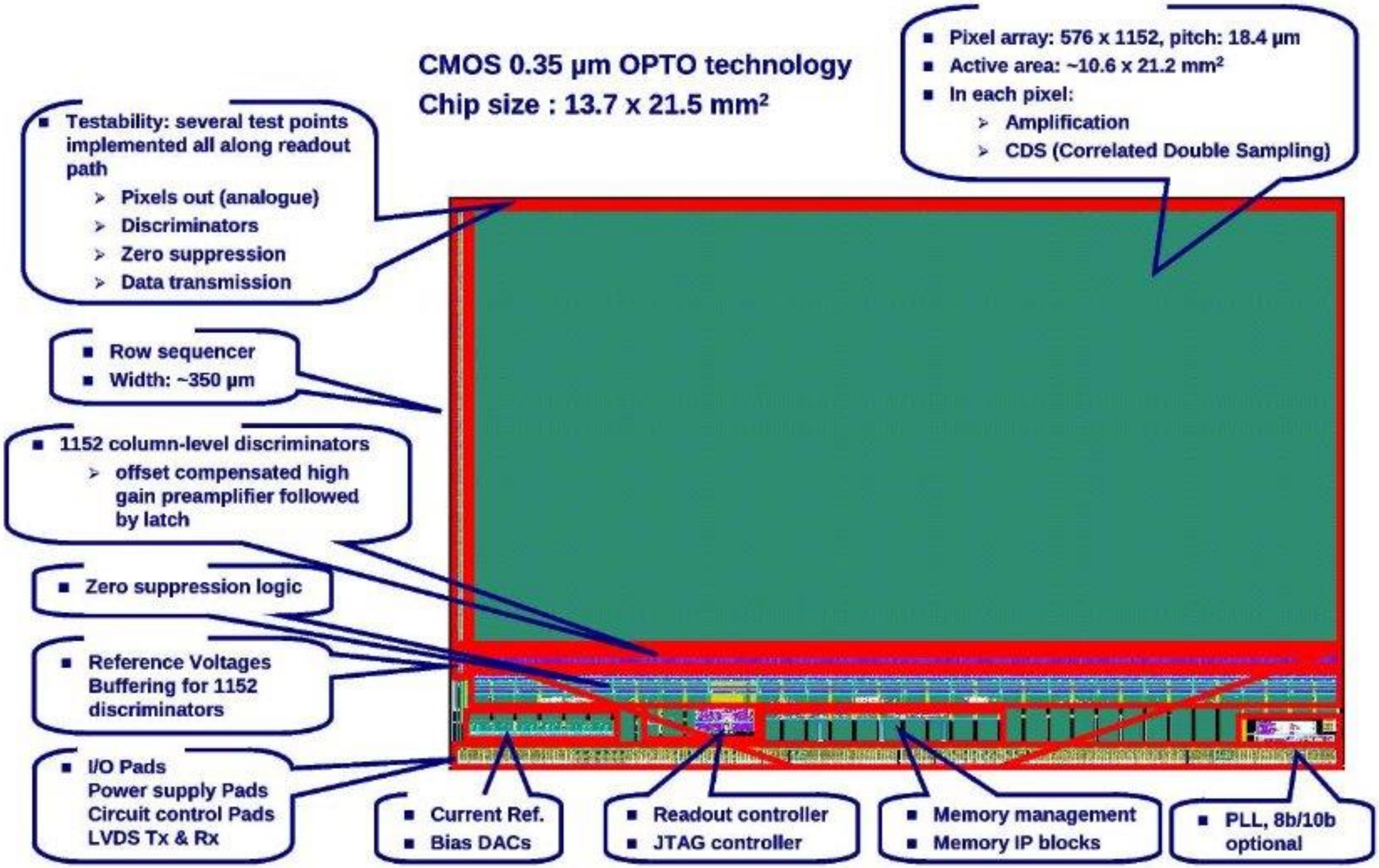
For the latest results on the MIMOSA32/34 see for example :
Serhiy Senyukov (IPHC-CNRS Strasbourg)on behalf of the PICSEL group, (IPRD13) 7 - 10 October 2013 Siena, Italy
http://www.bo.infn.it/sminiato/sm13/abstract/S2/s-senyukov.pdf

Brookhaven National Laboratory



BACK-UP Slides

MIMOSA-26: Functionality Implementation



Overview of the New Detector

- Si-Vertex
  - MAPS technology from IPHC ala STAR, CBM, Alice, …)
    - Barrel:

    4 double sided layers @ 3. 5.5 8. 15. cm 10 sectors in Φ
    - Forward Disks:

    4 single sided disks spaced in z starting from 20 cm, dual sided readout or GEM ?
- Barrel Tracking
  - Preferred technology TPC (alternative GEM-Barrel tracker Mass?)
    - Low mass, PID e/h via dE/dx
- Forward tracking
  - GEM-Trackers
- Forward/Backward RICH-Detectors
  - Momenta to be covered: 0.5-80 GeV for $1<|y|<4(5)$
  - Technology:
    - Dual Radiator (HERMES, LHCb) Aerogel+Gas (C_4F_{10} or C_4F_8O)
  - Photondetector: low sensitivity to magnetic field

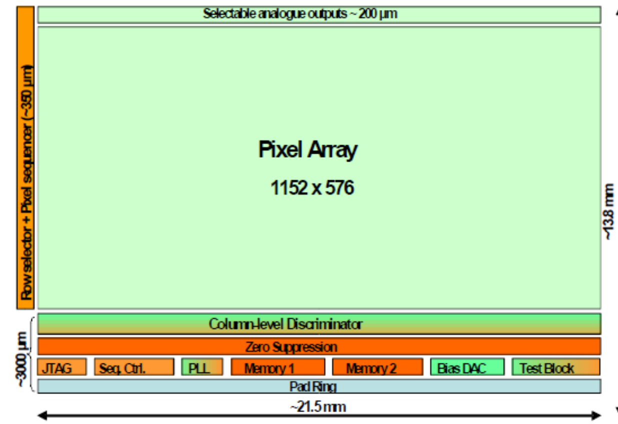
Overview of the New Detector

- Barrel PID-Detectors
  - Momenta to be covered 0.5-10 GeV for -1<y<1
  - Technology:
    - Aerogel Proximity focusing RICH
    - DIRC
- ECal:
  - Backward/Barrel:
    - PbW-crystal calorimeter → great resolution, small Molière radius → electron-ID: e/p, measure lepton via Ecal, important for DVCS
  - Forward:
    - Less demanding: sampling calorimeter
- Preshower
  - Si-W technology as proosed for PHENIX MPCEX
- Hcal/Muons-Detectors
  - Not obvious they are really needed
- Luminosity monitor, electron and hadron polarimeters

Silicon Vertex

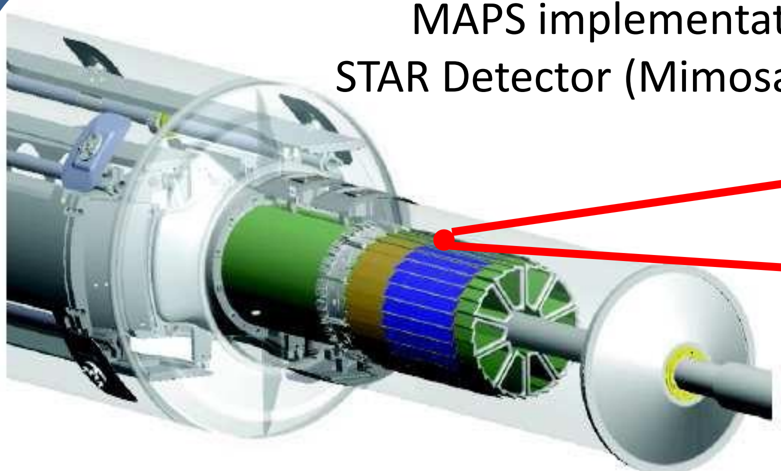
Mimosa 26 :

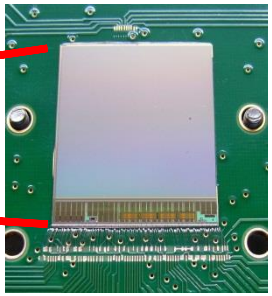
- ✓ Matrix of 663 552 pixels: 576 lines x 1152 col.
- ✓ 13.7 mm X 21.5 mm Matrix Surface
- ✓ Pitch= 18 μm
- ✓ Sensitive volume thickness 15 μm
- ✓ Digital data stream after zero suppression



See for details: http://www.iphc.cnrs.fr/List-of-MIMOSA-chips.html

MAPS implementation in the
STAR Detector (Mimosa 28 Ultimate)

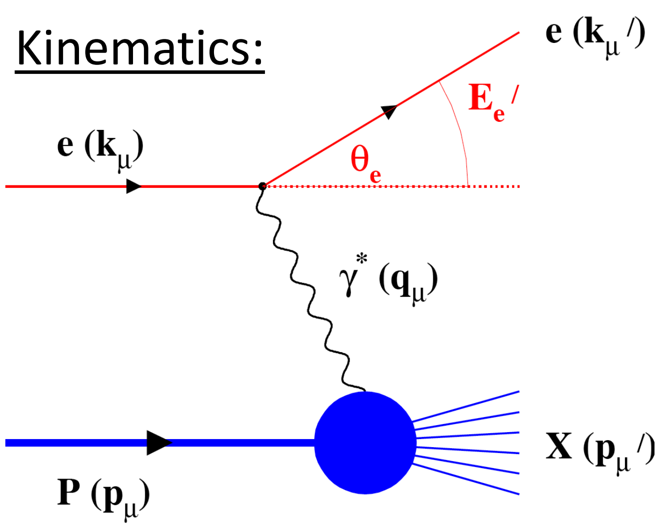




http://indico.scc.kit.edu/indico/getFile.py/
access?contribId=6&resId=0&materialId=slides&confId=27

How to see the gluons: Deep Inelastic Scattering

Kinematics:



$$Q^2 = -q^2 = -(k_\mu - k'_\mu)^2$$

$$Q^2 = 2E_e E'_e (1 - \cos\Theta_{e'})$$

Measure of resolution power

$$y = \frac{pq}{pk} = 1 - \frac{E'_e}{E_e}\cos^2\left(\frac{\theta'_e}{2}\right)$$

Measure of inelasticity

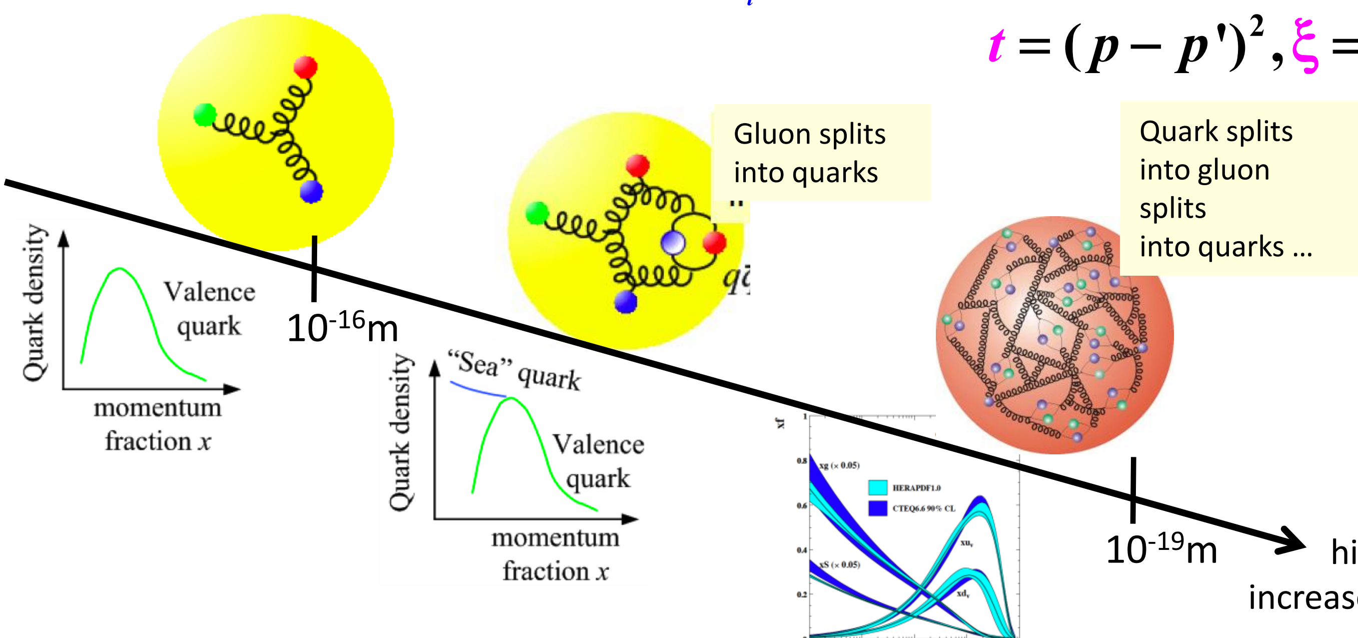
$$Hadron: z = \frac{E_h}{\nu};$$

$$x_B = \frac{Q^2}{2pq} = \frac{Q^2}{sy}$$

Measure of momentum fraction of struck quark

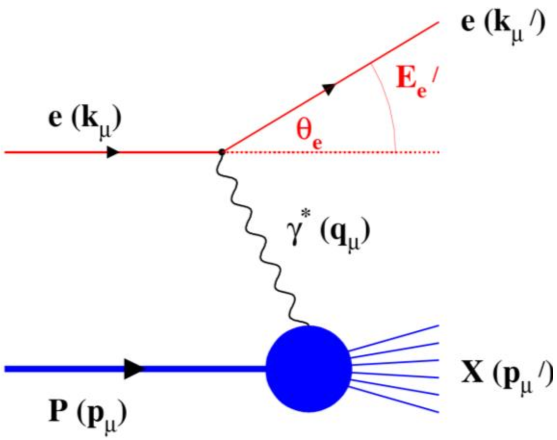
p_t^h: with respect to γ^*

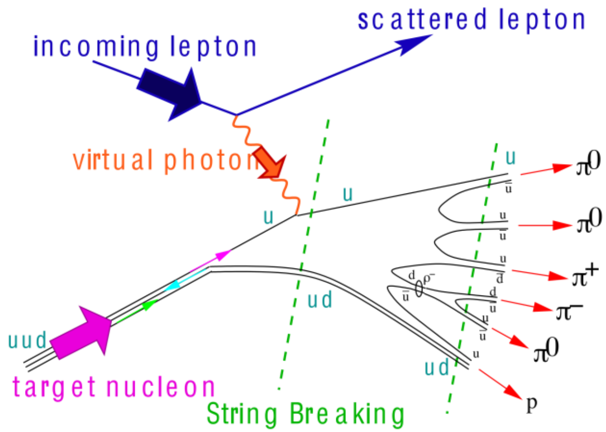
$$t = (p - p')^2, \xi = \frac{x_B}{2 - x_B}$$

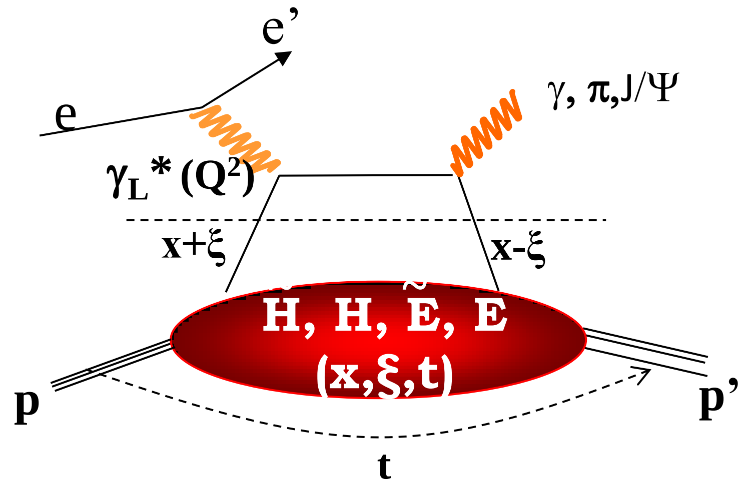


higher √s increases resolution

What needs to be covered







Inclusive Reactions:

- ❑ Momentum/energy and angular resolution of e' critical
- ❑ Very good electron id
- ❑ Moderate luminosity >10^{32} cm^{-1} s^{-1}
- ❑ Need low x ~10^{-4} → high √s (Saturation and spin physics)

Semi-inclusive Reactions:

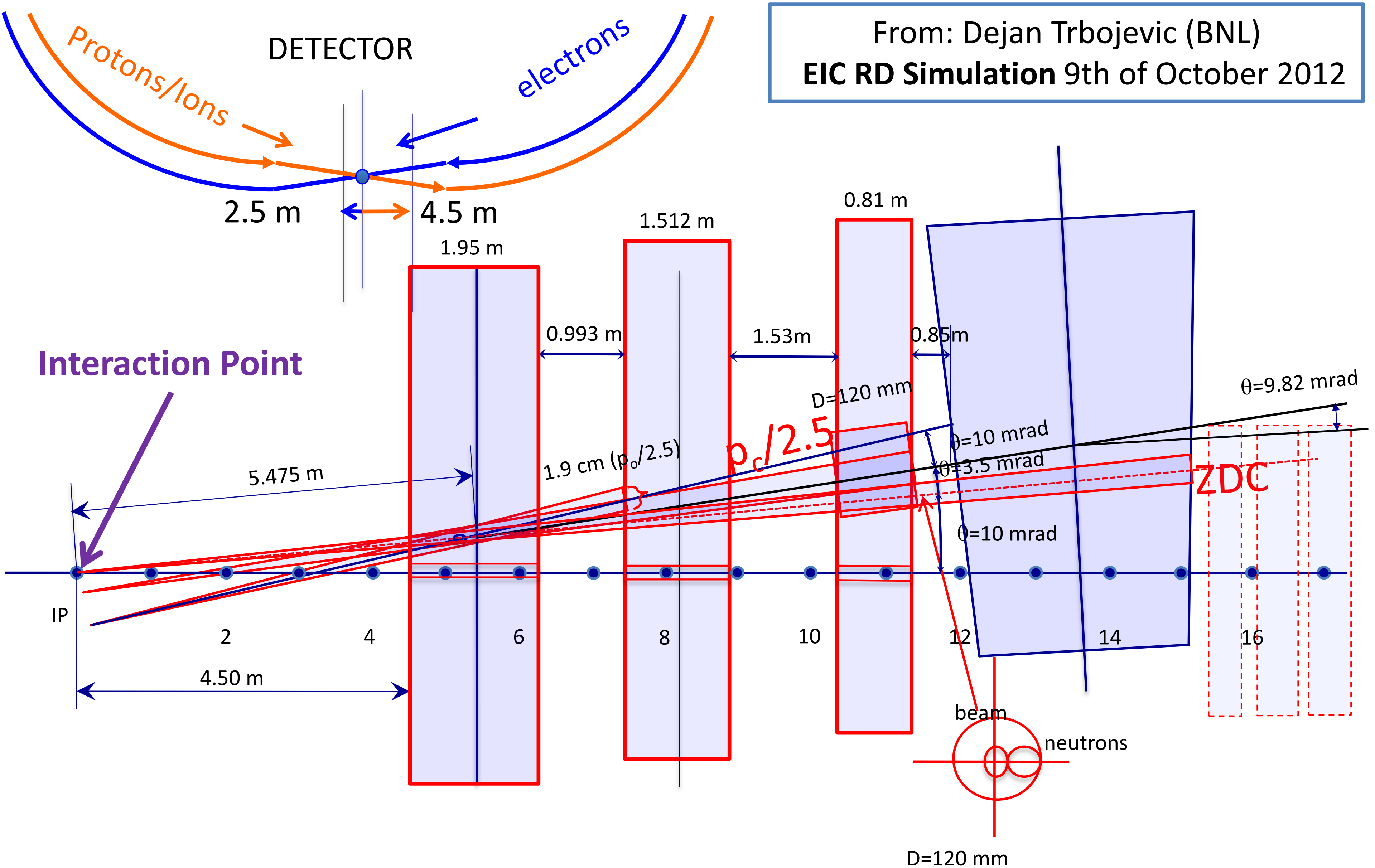
- ❑ Excellent particle ID: π,K,p separation over a wide range in η
- ❑ full Φ-coverage around γ*
- ❑ Excellent vertex resolution → Charm, bottom identification
- ❑ high luminosity >10^{33} cm^{-1} s^{-1} (5d binning (x,Q^2,z, p_t,Φ))
- ❑ Need low x ~10^{-4} → high √s

Exclusive Reactions:

- ❑ Exclusivity → high rapidity coverage → rapidity gap events
- ❑ high resolution in t → Roman pots
- ❑ high luminosity >10^{33} cm^{-1} s^{-1} (4d binning (x,Q^2,t,Φ))

IP configuration for eRHIC

From: Dejan Trbojevic (BNL)
EIC RD Simulation 9th of October 2012



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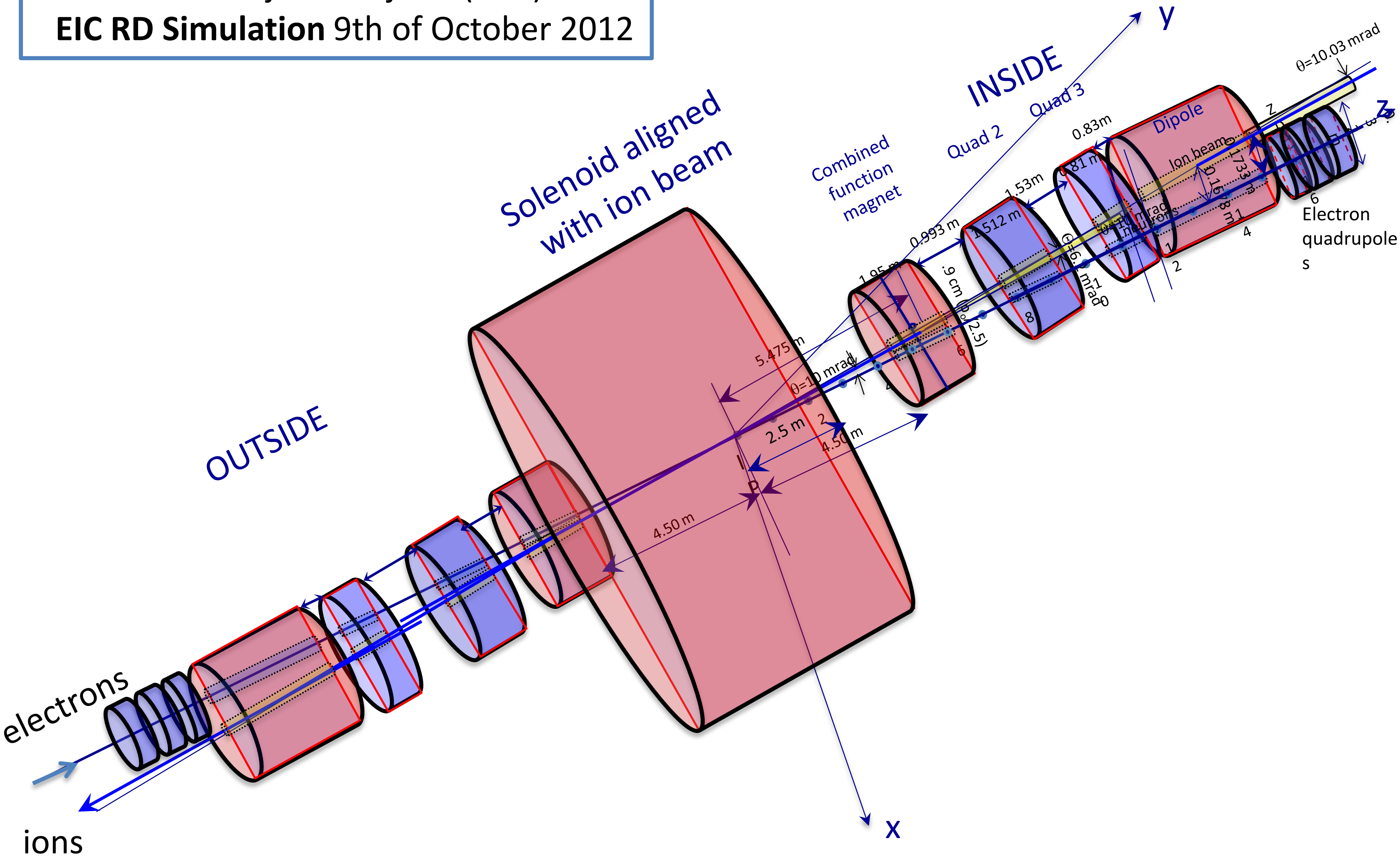
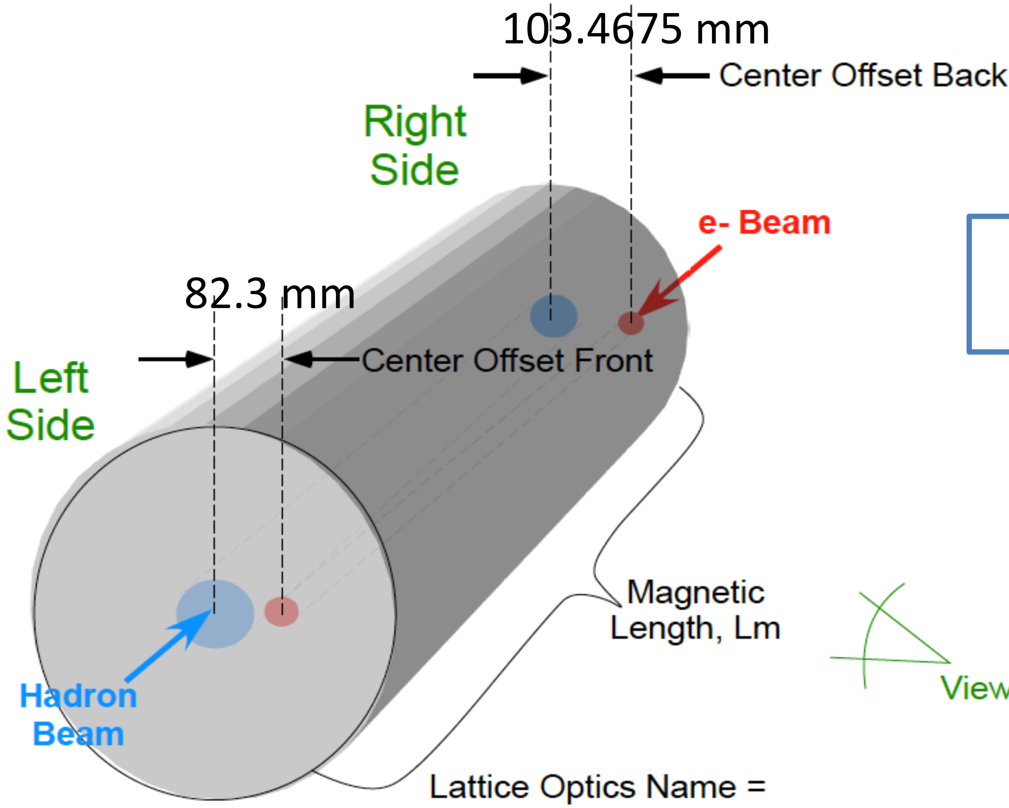


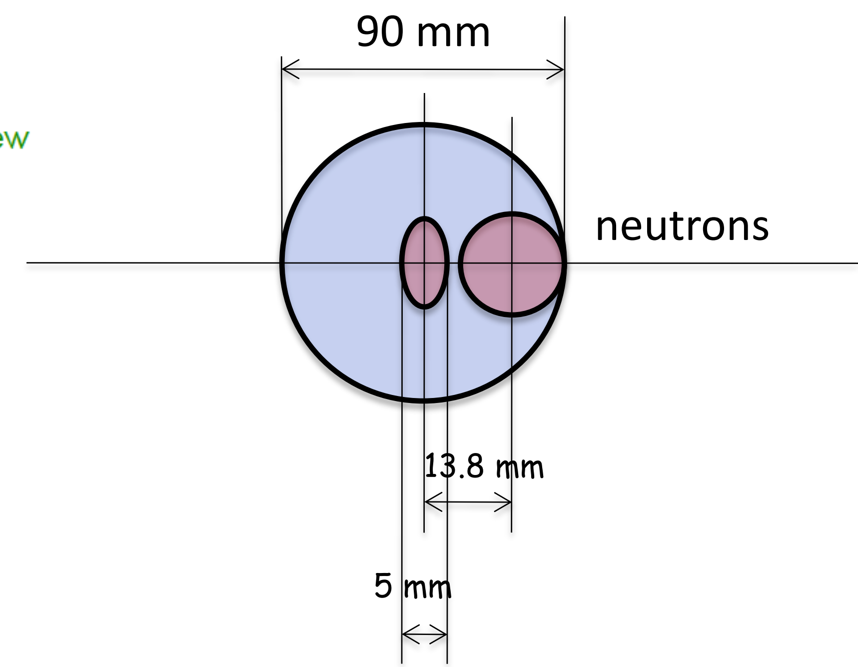
Q2



From: Dejan Trbojevic (BNL)
EIC RD Simulation 9th of October 2012

Lattice Optics Name =
IR Location (Right/Left) = Q2
Magnetic Length (m) = left
Gradient (T/m) = 1.5157 m
Residual Field at e-Beam axis (Gauss) = 200 T/m
Hadron Beam Clear Bore Diameter (mm) = 1 G
Electron Beam Clear Bore Diameter (mm) = 90 mm
E-beam Center Offset Front (mm) = 18 mm
E-Beam Center Offset Back (mm) = 82.3 mm
103.4675 mm
Name & Date filled Out

Hadron Aperture Q_2

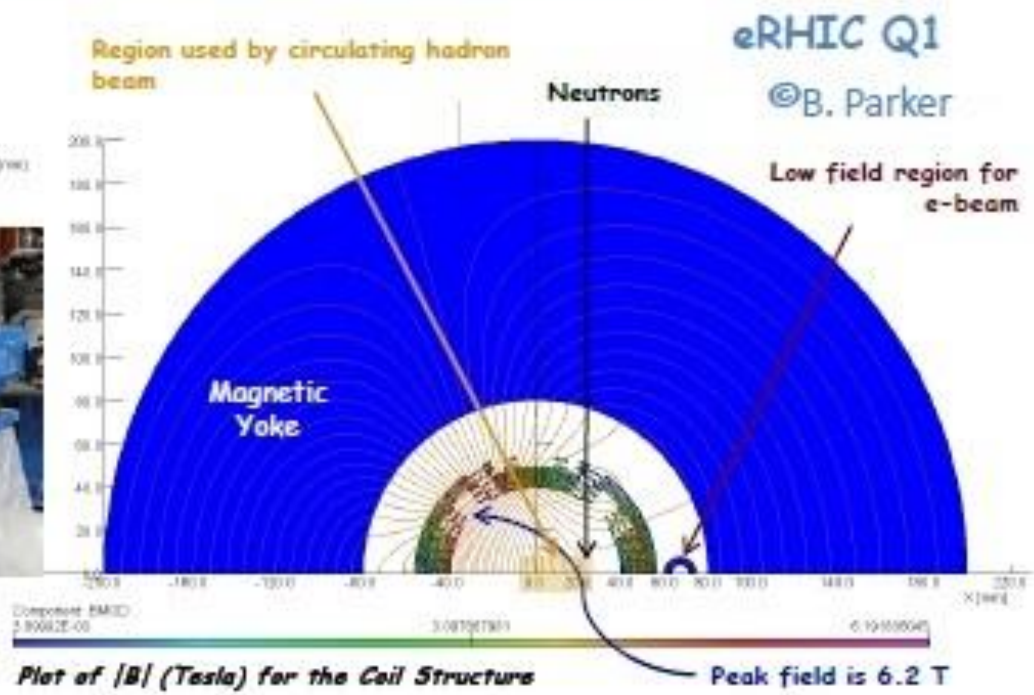


6•σ=6 •√ 916m1.2/6265.76=5 mm

The special IR magnet

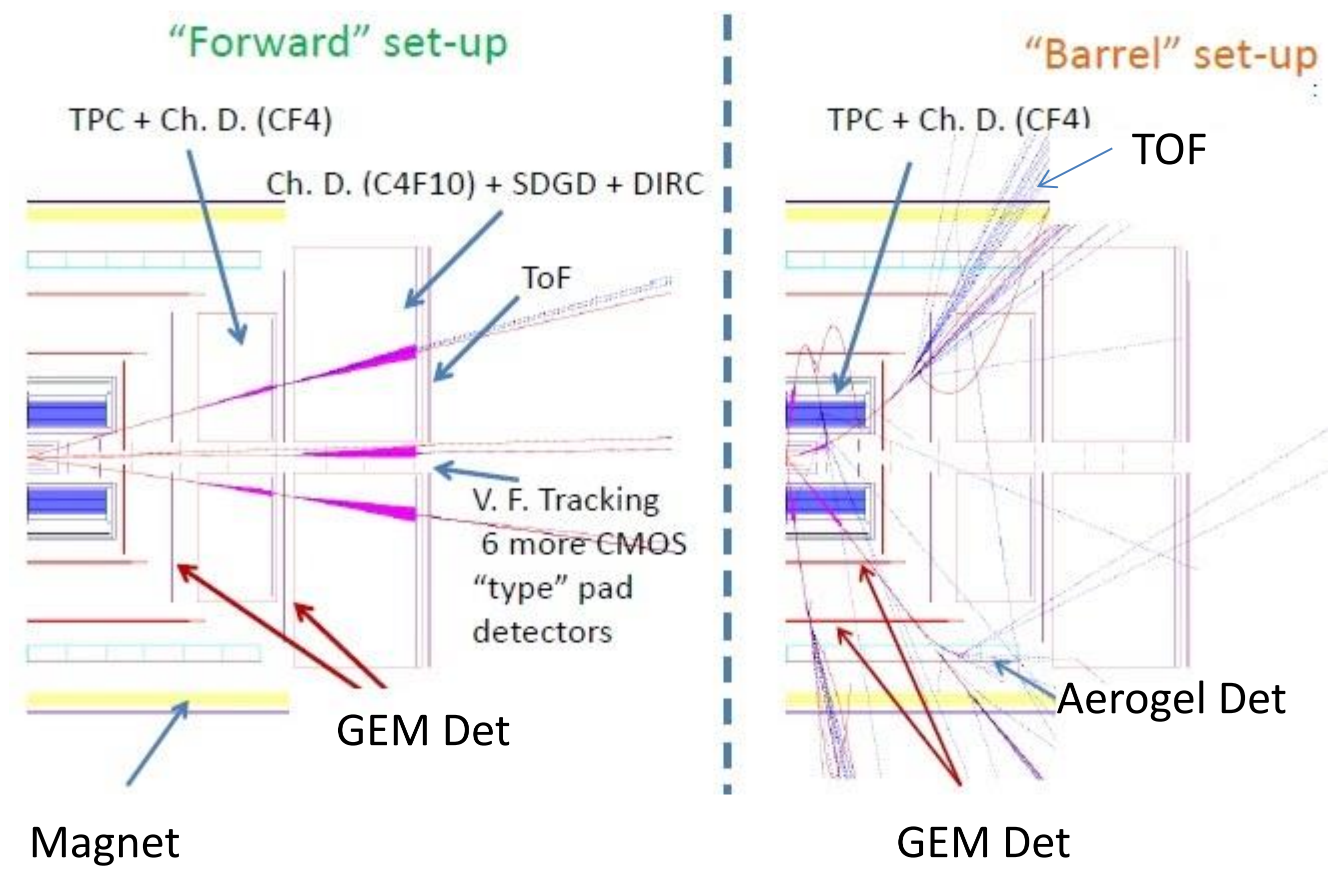
- Large aperture for passage of neutrons and gammas, circulating beam and off-momentum charged particle.
- Based on Nb_3Sn magnet technology developed for LHC IR upgrade

LHC IR magnet prototype



From: Y.Hao on behalf of eRHIC design team 2012 RHIC & AGS Annual User's Meeting

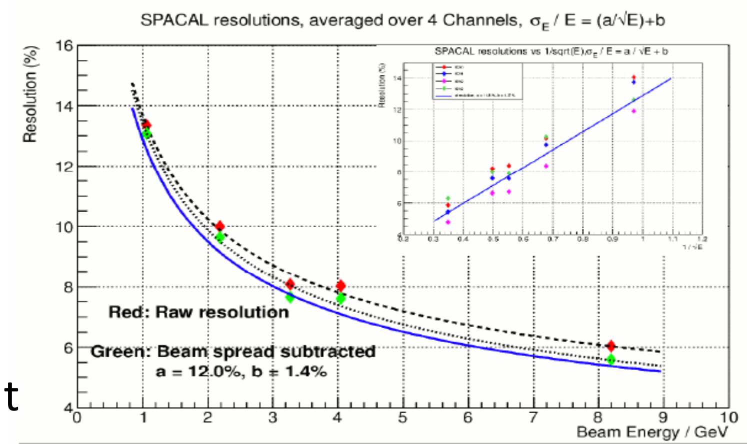
Tracking System



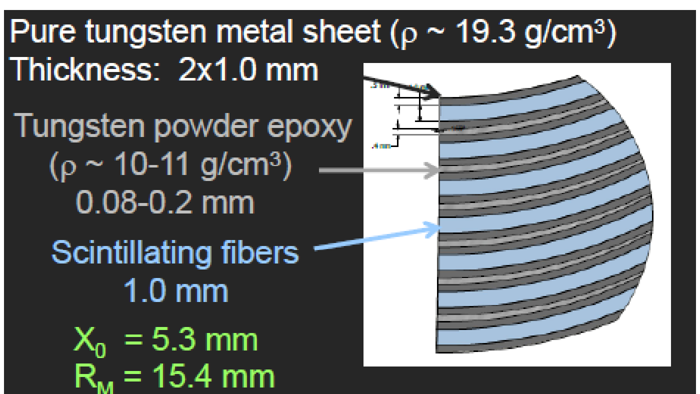
Calorimeters

New technologies under consideration:

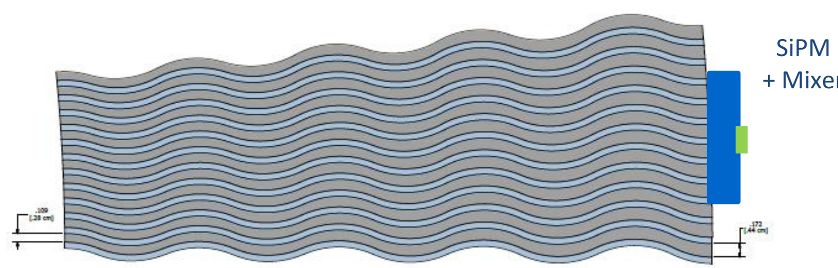
STAR Forward Calorimeter:Tungsten Powder/Epoxy/SciFi
O. Tsai, H. Huang (UCLA)



Fermilab Test Beam result



Tungsten-Scintillating Fiber
"Optical Accordion" EM Calorimeter

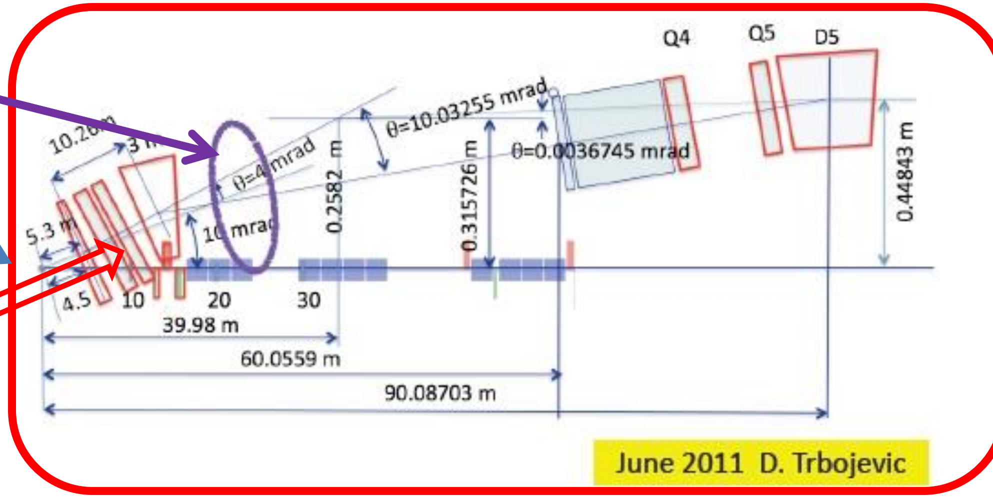


Roman Pots Studies

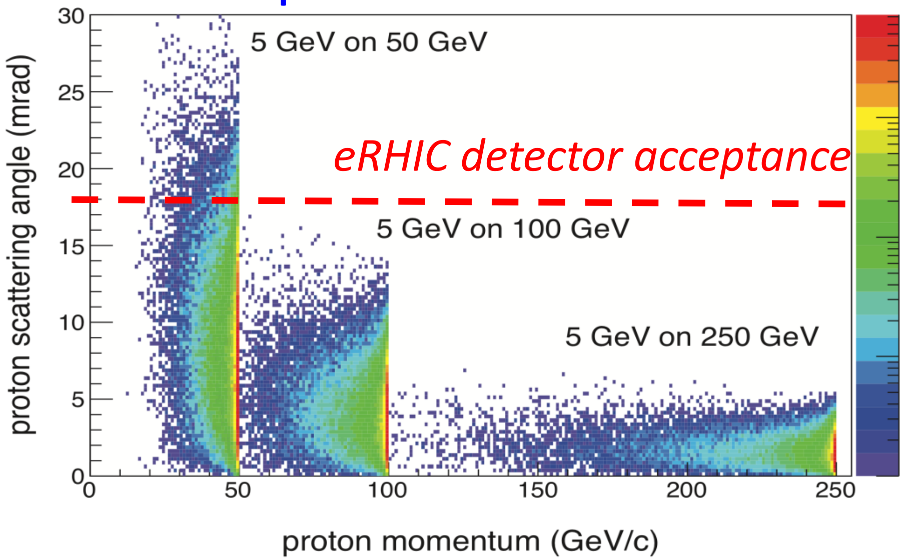
Roman Pots station
(20 – 22 m from IP)

Interaction Point

Hadron Beam Direction

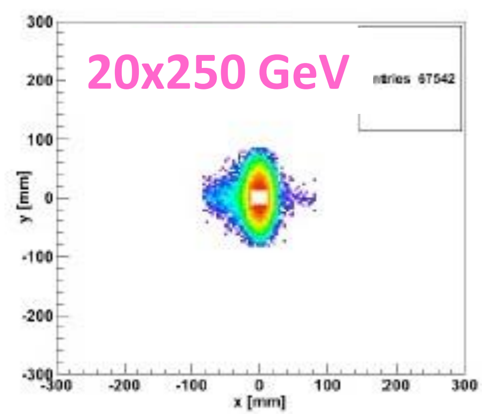


leading protons are never in the main detector acceptance at EIC



Main detector

Roman Pots



eRHIC Collider parameters (still valid?)

	e	p	$^{3}_{2}$He	$^{197}_{79}$Au	$^{238}_{92}$U
Energy, GeV	10	250	167	100	100
CM energy, GeV		100	82	63	63
Number of bunches/distance between bunches	107 nsec	111	111	111	111
Bunch intensity (nucleons)	$0.24 \cdot 10^{11}$	$4 \cdot 10^{11}$	$6 \cdot 10^{11}$	$6 \cdot 10^{11}$	$6.3 \cdot 10^{11}$
Bunch charge, nC	5.8	64	60	39	40
Beam current, A	0.05	0.556	0.556	0.335	0.338
Normalized emittance of hadrons 95% , mm mrad		1.2	1.2	1.2	1.2
Normalized emittance of electrons, rms, mm mrad		16	24	40	40
Polarization, %	80	70	70	none	none
RMS bunch length, cm	0.2	5	5	5	5
β*, cm	5	5	5	5	5
Luminosity per nucleon, $cm^{-2} s^{-1}$		**2.7×10^{34}**	**2.7×10^{34}**	**1.6×10^{34}**	**1.7×10^{34}**

Plots from J-H Lee

Roman Pots Studies